STUDIES ON THE THERMODYNAMICS OF THE ATMOSPHERE.

II.—COORDINATION OF THE VELOCITY, TEMPERATURE, AND PRESSURE IN THE CYCLONES AND ANTICYCLONES OF EUROPE AND NORTH AMERICA.

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THE ADOPTED MEAN TEMPERATURES AND GRADIENTS ON THE 1000-METER LEVELS FOR AMERICAN AND EUROPEAN CYCLONES AND ANTICYCLONES.

In order that we may have a suitable example for discussion in the application of the thermodynamic formulæ to the atmosphere, it will be profitable to adopt an average system of temperature distributions in cyclones and anticyclones, derived from the observations that have been made available by the computations of the preceding paper of this series. The practical difficulty of securing, by numerous ascensions at the same time, a sufficiently large number of accurate simultaneous observations in the several subareas around the barometric centers, for all the levels required up to 10,000 meters, is very great when one special temperature disturbance is to be observed, as in an individual storm. It would be desirable to make numerous simultaneous ascensions from different points of the same cyclone, as has been done in Europe, if it is possible to do so from many stations, say for 25 to 40 in number, but the result will then be to give the conditions in only one case, and it would of course require many similar groups of such ascensions to enable us to secure what may be accepted as the average or normal type of cyclonic temperature distribution. Repeated ascensions at a single station, where the facilities for the work are generally much more adequately elaborated, accomplish the same purpose by allowing the kites to remain aloft, and thus permitting the cyclone to drift past the instruments which register the varying changes of temperature, pressure, humidity, and wind velocity. By utilizing the numerous ascensions of kites and balloons made at Hald, Berlin, and Blue Hill, we can secure the approximate normal or average state of the temperatures with which to explain and test the proposed thermodynamic system. Owing to the incompleteness of our available data, it is necessary to assume some extensions of the probable temperatures beyond the actual observations, but it can be done without bringing into doubt the main principles involved in this discussion. The further acquisition of observed data by work in the future will correct any numerical errors that may now arise from this procedure. In order to establish the theory of the energy of storms which I have proposed, it seems proper to use the best available data in these preliminary computations, rather than wait for more completely satisfactory compilations of temperature observations. It will, also, facilitate a correct interpretation of the results of future balloon and kite ascensions, if we can show that our theory is capable of suitably explaining the present adopted mean system of temperature distributions in cyclones and anticyclones. We can infer from the preceding paper that the American and European observations at the three given stations in the lower levels approach so closely together in their numerical details on the 4000-meter level, that we shall be justified in adopting the European observations above 4000 meters as a fair representation of the conditions in the North American atmosphere, which, however, remains to be practically explored in the higher levels.

In order to concentrate the work of computation which will follow, we extract from Tables 1, 2, 3, 4, the temperatures, T, in centigrade degrees, for the several 1000-meter levels, as given in the last column of each quadrant. These temperatures appear in the left-hand section of Tables 9 and 10, which give the temperatures and variations of temperature on each 1000-meter level in American and European cyclones and anticyclones for the winter and for the summer. It should be noted that we have been obliged to introduce certain values for the north quadrant in the American data, because direct observations are entirely lacking, except in the winter high areas. The values here adopted have been the outcome of considerable labor, and they may be found to need some modification as the result of other direct observations. I have been guided in the determination of the interpolated temperatures by three different considerations, (1) the relations of the center areas to the north areas in general, (2) the comparison of the European data with the American, and finally, (3) the balance of the entire system, consisting of the four sectors of the high areas and the four sectors of the low areas taken in connection with the mean temperatures and gradients of the atmosphere without regard to any cyclonic disturbances. Thus, having adopted the mean temperatures and gradients of Table 11 and the mean variations in seven sectors of Table 9, it is easy to compute the variation in any missing quadrant, as the north. A complete balance must evidently be maintained, because the sum of the excess and defect of the temperatures in the several areas on a given level of the cyclone and anticyclone at any elevation, as 1000 meters, 2000 meters, etc., must be equal to zero. However, in these papers, as we are concerned only with approximate relative disturbances of the temperature, and since individual cyclonic disturbances differ widely from any normal type that may be adopted, such interpolations may be admitted for the purpose of discussion.

TABLE 9.—*Temperatures and variations of temperature on each 1000-meter level in American cyclones and anticyclones.*

Height in meters.	Temperatures T. N.	E.	S.	W.	Means. T.	Variations $-\Delta T$. N.	E.	S.	W.	Mean $-\Delta T$.
	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.
AMERICAN WINTER HIGH AREAS.—From Table 1.										
6000	......	......	......	......	—26.0	......	......	......	......	....
5000	......	......	......	......	—19.5	......	......	......	......	....
4000	— 7.9	—18.8	—17.9	— 7.6	—14.0	+ 6.1	— 4.8	— 3.9	+ 6.4	....
3000	— 3.9	—12.7	—12.6	— 3.1	— 9.0	+ 5.1	— 3.7	— 3.6	+ 5.9	....
2000	— 1.2	— 7.1	— 8.3	1.0	— 4.8	+ 3.6	— 2.3	— 3.5	+ 5.8	....
1000	1.8	— 3.5	— 3.6	4.5	— 1.5	+ 3.3	— 2.0	— 2.1	+ 6.0	....
0	3.7	2.0	— 0.7	9.0	2.8	+ 0.9	— 0.8	— 3.5	+ 6.2	....
AMERICAN WINTER LOW AREAS.—From Table 1.										
6000	......	......	......	......	—26.0	......	......	......	......	....
5000	......	......	......	......	—19.5	......	......	......	......	....
4000	(—12.0)	—13.2	—18.7	—16.0	—14.0	+ 2.0	+ 0.8	— 4.7	— 2.0	3.84
3000	(— 7.0)	— 8.1	—12.6	—11.6	— 9.0	+ 2.0	+ 0.9	— 3.6	— 2.6	3.43
2000	(— 2.0)	— 3.0	— 6.3	— 7.8	— 4.8	+ 2.8	+ 1.8	— 1.5	— 3.0	3.04
1000	(— 2.0)	— 2.7	— 0.1	— 6.8	— 1.5	— 0.5	— 1.2	+ 1.4	— 5.3	2.73
0	(2.0)	2.8	6.3	— 2.7	2.8	— 0.8	0.0	+ 3.5	— 5.5	2.65
									Mean	3.14
AMERICAN SUMMER HIGH AREAS.—From Table 2.										
6000	......	......	......	......	—20.6	......	......	......	......	....
5000	......	......	......	......	—14.1	......	......	......	......	....
4000	— 3.0	— 8.4	— 9.6	— 4.8	— 7.1	+ 4.1	— 1.3	— 2.5	+ 2.3	....
3000	3.6	0.1	— 0.6	2.0	0.4	+ 3.2	— 0.3	— 1.0	+ 1.6	....
2000	9.4	7.1	5.8	8.1	6.4	+ 3.0	+ 0.7	— 0.6	+ 1.7	....
1000	13.6	13.0	11.2	12.1	11.8	+ 1.8	+ 1.2	— 0.6	+ 0.3	....
0	17.9	16.7	14.5	18.1	17.2	+ 0.7	— 0.5	— 2.7	+ 0.9	....
AMERICAN SUMMER LOW AREAS.—From Table 2.										
6000	......	......	......	......	—20.6	......	......	......	......	....
5000	......	......	......	......	—14.1	......	......	......	......	....
4000	—11.4	— 6.0	— 3.6	— 9.0	— 7.1	— 4.3	+ 1.1	+ 3.5	— 1.9	2.63
3000	— 1.4	— 0.3	3.1	— 3.3	0.4	— 1.8	— 0.7	+ 2.7	— 3.7	1.88
2000	4.1	4.8	8.9	3.0	6.4	— 2.3	— 1.6	+ 2.5	— 3.4	1.98
1000	9.5	10.2	16.0	8.8	11.8	— 2.3	— 1.6	+ 4.2	— 3.0	2.00
0	14.7	15.6	23.2	16.9	17.2	— 2.5	— 1.6	+ 6.0	— 0.3	1.53
									Mean	2.00

We next take the mean temperatures of all the high and low areas for the four available systems, the American winter and summer up to 4000 meters, and the European winter and summer up to about 10,000 meters, and set them in the middle column of Tables 9 and 10, as well as in Table 11, the adopted mean temperatures and gradients on the 1000-meter levels for American and European cyclones and anticyclones. It will be seen that at the 4000-meter level the temperatures are almost exactly equal in the two regions, for winter —14.0°

TABLE 10.—*Temperatures and variations of temperature on each 1000-meter level in European cyclones and anticyclones.*

EUROPEAN WINTER HIGH AREAS.—From Table 3.

Height in meters.	Temperatures T. N.	E.	S.	W.	Means. T.	Variations $-\Delta T$. N.	E.	S.	W.	Mean $-\Delta T$.
	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.
6000......	—27.0	—33.2	—24.5	—21.6	—27.4	+ 0.4	— 5.8	+ 2.9	+ 5.8	....
5000......	—19.4	—24.0	—18.3	—14.5	—20.4	+ 1.0	— 3.6	+ 2.1	+ 5.9	....
4000......	—12.9	—18.0	—12.9	— 8.5	—14.5	+ 1.6	— 3.5	+ 1.6	+ 6.0	....
3000......	— 7.6	—13.2	— 7.9	— 3.3	— 9.0	+ 1.4	— 4.2	+ 1.1	+ 5.7	....
2000......	— 2.5	— 9.0	— 5.4	0.5	— 4.1	+ 1.6	— 4.9	— 1.3	+ 4.6	....
1000......	0.6	— 3.8	— 2.6	2.8	0.3	+ 0.3	— 4.1	— 2.9	+ 2.5	....
0......	4.6	0.8	0.8	4.1	4.3	+ 0.3	— 3.5	— 3.5	— 0.2	....

EUROPEAN WINTER LOW AREAS.—From Table 3.

Height in meters.	N.	E.	S.	W.	Means. T.	N.	E.	S.	W.	Mean $-\Delta T$.
6000......	—26.5	—29.6	—27.8	—29.0	—27.4	+ 0.9	— 2.2	— 0.4	— 1.6	2.50
5000......	—19.2	—22.4	—21.7	—23.8	—20.4	+ 1.2	— 2.0	— 1.3	— 3.4	2.56
4000......	—13.0	—16.0	—15.4	—19.5	—14.5	+ 1.5	— 1.5	— 0.9	— 5.0	2.70
3000......	— 6.6	—10.0	—10.0	—13.2	— 9.0	+ 2.4	— 1.0	— 1.0	— 4.2	2.63
2000......	— 1.5	— 5.0	— 4.2	— 5.5	— 4.1	+ 2.6	— 0.9	— 0.1	— 1.4	2.18
1000......	2.1	1.0	1.4	0.5	0.3	+ 1.8	+ 0.7	+ 1.1	+ 0.2	1.70
0......	6.9	4.2	6.6	6.5	4.3	+ 2.6	— 0.1	+ 2.3	+ 2.2	1.83
						Mean from 0 to 4000 meters,				2.21

EUROPEAN SUMMER HIGH AREAS.—From Table 4.

Height in meters.	N.	E.	S.	W.	Means. T.	N.	E.	S.	W.	Mean $-\Delta T$.
6000......	—16.7	—24.3	—18.9	—16.7	—19.1	+ 2.4	— 5.2	+ 0.2	+ 2.4	....
5000......	—10.6	—17.2	—13.1	—10.2	—13.0	+ 2.4	— 4.2	— 0.1	+ 2.8	....
4000	— 4.8	—11.2	— 7.7	— 4.2	— 7.2	+ 2.4	— 4.0	— 0.5	+ 3.0	....
3000.. ...	— 0.4	— 6.5	— 1.7	0.8	— 2.1	+ 1.7	— 4.4	+ 0.4	+ 2.9	....
2000......	2.7	— 2.9	2.6	5.9	2.2	+ 0.5	— 5.1	+ 0.4	+ 3.7	....
1000	6.8	3.8	7.4	9.8	8.1	— 1.3	— 4.3	— 0.7	+ 1.7	....
0......	13.7	11.3	12.8	14.0	14.1	— 0.4	— 2.8	— 1.3	— 0.1	....

EUROPEAN SUMMER LOW AREAS.—From Table 4.

Height in meters.	N.	E.	S.	W.	Means. T.	N.	E.	S.	W.	Mean $-\Delta T$.
6000......	—13.3	—18.2	—21.9	—23.0	—19.1	+ 5.8	+ 0.9	— 2.8	— 3.9	2.95
5000......	— 7.8	—11.6	—16.1	—17.1	—13.0	+ 5.2	+ 1.4	— 3.1	— 4.1	2.91
4000......	— 2.8	— 5.9	—10.6	—10.5	— 7.2	+ 4.4	+ 1.3	— 3.4	— 3.3	2.79
3000......	2.0	— 0.8	— 5.9	— 4.7	— 2.1	+ 4.1	+ 1.3	— 3.8	— 2.6	2.65
2000......	6.4	4.2	— 0.4	— 0.9	2.2	+ 4.2	+ 2.0	— 2.6	— 3.1	2.70
1000......	12.5	12.0	5.7	6.7	8.1	+ 4.4	+ 3.9	— 2.4	— 1.4	2.51
0......	16.8	17.3	13.5	13.4	14.1	+ 2.7	+ 3.2	— 0.6	— 0.7	1.48
						Mean from 0 to 4000 meters,				2.43

TABLE 11.—*Adopted mean temperatures and gradients on the 1000-meter levels for American and European cyclones and anticyclones.*

Height in meters.	Winter. American. T	$\frac{\Delta T}{1000}$	Winter. European. T	$\frac{\Delta T}{1000}$	Summer. American. T	$\frac{\Delta T}{1000}$	Summer. European. T	$\frac{\Delta T}{1000}$
	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.
16000	—73.9		—75.4		—72.2		—71.1	
		—3.5		—3.5		—4.0		—3.0
15000	—70.4		—71.9		—68.2		—68.1	
		—3.0		—3.0		—3.0		—2.5
14000	—67.4		—68.9		—65.2		—65.6	
		—2.5		—2.5		—3.0		—2.5
13000	—64.9		—66.4		—62.2		—63.1	
		—2.0		—2.0		—4.0		—4.0
12000	—62.9		—64.4		—58.2		—59.1	
		—4.0		—4.0		—5.5		—5.5
11000	—58.9		—60.4		—52.7		—53.6	
		—5.5		—5.5		—6.0		—6.5
10000	—53.4		—54.9		—46.7		—47.1	
		—6.5		—6.5		—6.7		—7.0
9000	—46.9		—48.4		—40.0		—40.1	
		—7.1		—7.0		—7.0		—7.5
8000	—39.8		—41.4		—33.0		—32.6	
		—7.0		—7.0		—6.5		—7.0
7000	—32.8		—34.4		—26.5		—25.6	
		—6.8		—7.0		—5.9		—6.5
6000	—26.0		—27.4		—20.6		—19.1	
		—6.5		—7.0		—6.5		—6.1
5000	—19.5		—20.4		—14.1		—13.0	
		—5.5		—5.9		—7.0		—5.8
4000	—14.0		—14.5		— 7.1		— 7.2	
		—5.0		—5.5		—7.5		—5.1
3000	— 9.0		— 9.0		+ 0.4		— 2.1	
		—4.7		—4.9		—6.0		—4.3
2000	— 4.3		— 4.1		+ 6.4		+ 2.2	
		—2.8		—4.4		—5.4		—5.9
1000	— 1.5		+ 0.3		+11.8		+ 8.1	
		—4.3		—4.0		—5.4		—6.0
000	+ 2.8		+ 4.3		+17.2		+14.1	

and —14.5°, and for summer —7.1° and —7.2°, respectively, for America and Europe. This indicates that, after escaping from the confusion in the circulation near the surface, about the same temperatures prevail in the midst of the track of the cyclones and anticyclones in the Northern Hemisphere, that is over Blue Hill, latitude 42°, in the United States, and over Hald, latitude 56°, and Berlin, latitude 52°, in Europe, though the stations are themselves in different latitudes. We can, therefore, admit the European data to apply to the American temperatures above the 4000-meter level, at least approximately.

I have also, in Table 11, extended the temperatures and gradients up to 16,000 meters, using the known temperatures derived from European observations so far as possible in these high elevations, because I wish to secure some tentative values of the pressure, the density, and the gas factor at those altitudes, to be computed by the formula which will be introduced in the following paper of this series. It should be observed that the gradients are smaller in the lower levels than in the middle levels, 4000 to 10,000 meters, and that they are again smaller in the high levels above 10,000 meters. This type of variation in the gradients conforms to the warm zone observed by Teisserenc de Bort at the high levels, his "isothermal" zone, so that there are in the atmosphere two zones of relatively small gradients, the lower near the surface, from 0 to 4000 meters, and the higher above 10,000 meters. In these zones there are rapid alternations in temperature, as compared with the middle zone, showing that mixing currents prevail in these two strata of the atmosphere, the lower, near the surface, being the region where the cyclones and anticyclones are generated by the counterflow of warm and cold currents, and the latter, in the high levels, where the warm air overflowing from the Tropics mixes with cold air from the polar zones. As this is a subject belonging to the general circulation, further discussion of it will be postponed to a later paper. It should also be noted that I have gradually eliminated the annual variation in the temperature in the levels above 4000 meters, which is, I suppose, in agreement with the observed temperatures in the high levels. These adopted data will at least serve as examples, approximate to the truth, for introduction into the thermodynamic discussions to follow.

THE VARIATIONS OF TEMPERATURE IN THE SEVERAL SECTORS OF CYCLONES AND ANTICYCLONES ON EACH 1000-METER LEVEL.

Having derived from numerous direct observations the approximate normal temperatures prevailing in typical cyclones and anticyclones, I proceed to deduce a somewhat better average system of temperatures by the following discussion:

If T_0 is the mean or undisturbed temperature which prevails at a given level, independent of any local cyclonic disturbance, and T the temperature at a given disturbed point, as in the several sectors of the high and low areas, then $T_0 = T + \Delta T$, and $-\Delta T = T - T_0$ is the correction to transpose the mean T_0 into the observed T. Thus, in Table 9, under American winter high areas, at the north sector of the 4000-meter level, the temperature is —7.9°, which is +6.1° warmer than the mean temperature of that level —14.0°, taken over the combined high and low areas of the region. The variations ΔT of the second section of Tables 9 and 10 are, therefore, the corrections to change the mean T_0 to the observed temperature T, in which the sign + means warmer, and the sign — colder than the average temperature T_0. An inspection of these tables will show the prevailing temperature variations in the several quadrants, and a comparison of the American with the European variations up to 4000 meters shows the extent to which the data fail to conform precisely. Allowance must, of course, be made for the fact that Blue Hill is near the ocean on the eastern side of a great continent, and Hald and Berlin on the northwestern side of another continent, so that the permanent masses of air, as the high areas to the northwest of Blue Hill in winter, but to the northeast of Hald and Berlin, or the high area to the southeast of Blue Hill in summer, and to the southwest of Hald and Berlin, must necessarily make differences as to the temperature configurations of the several quadrants in the American and European systems. We have been proceeding on the assumption that the northern sector of the cyclone contains the "saddle" of pressure described in my papers on the barometric distribution, and while I have found it actually oriented in any one of the four quadrants at different times, yet it is situated to the north of the center in the great majority of instances for the United States.

If the mean variation of ΔT is computed up to 4000 meters, without regard to sign, to show the average relative distortion in the temperature level surfaces, we find for the—

American winter areas, the mean $\Delta T = 3.14$,
American summer areas, the mean $\Delta T = 2.00$,
European winter areas, the mean $\Delta T = 2.21$,
European summer areas, the mean $\Delta T = 2.43$.

The American winter disturbance is 1.57 times that of summer; the European winter disturbance is 0.91 time that of the summer; the American winter disturbance is 1.42 times that of Europe; and the American summer disturbance is 0.82 time that of Europe. On the whole the disturbances of temperature were about the same in each of these districts in the weather conditions when the direct observations made in balloon and kite ascensions were executed. What the relative values are in more strongly developed storms remains to be determined by further investigations.

In order to construct the mean temperature variations, ΔT, adopted in Table 12, we proceeded as follows: The variations of Tables 9 and 10 were plotted on diagrams like fig. 5, the American up to 4000 meters, the European up to 6000 meters, and then lines dividing the warm areas from the cold areas were drawn, the result showing that there is a similar configuration in spite of minor differences. Then the mean values of these two systems were taken, that is, the arithmetical means of the several pairs of American and European values in the same sector, so that the two observed systems were reduced to one system, which made another drawing like fig. 5. The sequence of the numbers in the same sector from the ground up through the several levels, such as appear in Table 12, was then examined, and, on the assumption that the change from one level to another should be gradual, and in harmony with those above and below, it was possible to detect imperfections in the observational data. There were not many important changes necessary to be made, and the final changes can be checked by the reader from Table 13, which is the adopted mean system taken by averaging Tables 9 and 10, together with the occasional minor corrections mentioned. These gradient variations, that is, the ΔT of Table 12, can be checked in the following way: The sum of the variations, ΔT, found on the same level, as 10,000, 9000, etc., should be zero, if the adjustments are relatively perfect. An examination of the check sums shows that they conform sufficiently for our purposes, as already defined. The vertical sequence of the numbers in the several sectors, N., E., S., W., of the high and low areas, winter and summer, now harmonizes so far as minor irregularities in our observational data are concerned, but it will be proper to modify this adopted system whenever suitable evidence of any important inaccuracy can be procured.

We may observe that, generally, the north and west sectors of the winter high areas are warm throughout, the east is cool in the high, and warm in the low, while an inversion of temperature takes place in the south sector. The last sector, to some extent, conforms to Professor Hann's inversion data, but the other sectors do not confirm his view. In the winter low areas the north and east sectors are warm, the west is cool, and the south again inverts. In the summer high areas the east sector is cool, the west is warm, and the north is warm up to 7000 meters, while the south inverts at 5000 meters from cool to warm; in the low areas the north and east sectors are warm, and the south and west sectors are generally cool.

TABLE 12.—*Adopted mean temperature variations, $-\Delta T$, in American and European cyclones and anticyclones.*

Height in meters.	Mean temperature. T	Mean temperature. $-\Delta T$	High areas. $T-T_0=-\Delta T$ N.	E.	S.	W.	Low areas. $T-T_0=-\Delta T$ N.	E.	S.	W.	Check sums.	
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
WINTER.												
10000	−54.2		−1.0	−2.0	+0.5	+2.0	+2.2	+3.0	−2.0	−2.8	+ 7.7	− 7.8
		−6.5										
9000	−47.7		−0.5	−2.5	+0.9	+2.4	+2.0	+3.0	−2.2	−3.0	+ 8.3	− 8.2
		−7.1										
8000	−40.6		+0.0	−3.0	+1.3	+3.0	+1.5	+2.7	−2.5	−3.3	+ 8.5	− 8.8
		−7.0										
7000	−33.6		+0.7	−3.5	+1.5	+4.0	+1.2	+2.5	−2.6	−3.5	+ 9.9	− 9.6
		−6.9										
6000	−26.7		+1.4	−4.0	+1.2	+5.0	+1.1	+2.2	−2.8	−3.8	+10.9	−10.6
		−6.7										
5000	−20.0		+2.0	−4.6	0.0	+5.7	+1.2	+2.0	−2.8	−4.0	+10.9	−11.4
		−5.7										
4000	−14.3		+2.8	−4.3	−1.2	+5.6	+1.8	+1.8	−2.4	−3.5	+12.0	−11.4
		−5.3										
3000	− 9.0		+2.7	−4.0	−1.3	+4.8	+2.2	+1.4	−2.3	−3.4	+11.1	−11.0
		−4.8										
2000	− 4.2		+2.0	−3.8	−2.7	+4.0	+2.4	+1.2	−1.3	−3.0	+ 9.6	−10.8
		−3.6										
1000	− 0.6		+1.5	−3.1	−2.5	+3.3	+1.7	+1.3	+1.1	−2.2	+ 8.9	− 7.8
		−4.2										
0	+ 3.6		+0.6	−2.1	−3.5	+2.0	+0.9	+1.1	+2.9	−1.7	+ 7.5	− 7.3
SUMMER.												
10000	−46.9		−1.2	−1.5	+0.2	+1.0	+4.8	+1.2	−2.0	−2.5	+ 7.2	− 7.2
		−6.8										
9000	−40.1		−0.6	−2.0	+0.5	+1.5	+4.6	+1.2	−2.3	−2.8	+ 7.8	− 7.7
		−7.3										
8000	−32.8		−0.0	−2.5	+1.0	+1.8	+4.4	+1.0	−2.7	−3.0	+ 8.2	− 8.2
		−6.7										
7000	−26.1		+0.7	−3.0	+1.5	+2.0	+4.2	+1.2	−3.0	−3.2	+ 9.6	− 9.2
		−6.2										
6000	−19.9		+1.4	−3.3	+1.2	+2.4	+4.0	+1.4	−3.0	−3.5	+10.4	− 9.8
		−6.3										
5000	−13.6		+1.9	−3.2	−0.1	+2.8	+3.3	+1.4	−2.7	−3.0	+ 9.4	− 9.0
		−6.4										
4000	− 7.2		+2.3	−3.2	−0.5	+2.2	+2.8	+1.3	−2.0	−2.6	+ 8.6	− 8.3
		−6.3										
3000	− 0.9		+1.9	−2.9	−0.4	+2.0	+2.4	+0.3	−1.0	−2.6	+ 6.6	− 6.9
		−5.2										
2000	+ 4.3		+1.4	−2.2	−0.4	+1.6	+1.9	+0.2	0.0	−2.4	+ 5.1	− 5.0
		−5.7										
1000	+10.0		+0.5	−1.9	−1.2	+1.0	+1.2	+0.4	+1.0	−2.2	+ 4.1	− 5.3
		−5.7										
0	+15.7		+0.2	−1.6	−2.0	+0.4	+0.8	+0.8	+2.8	−1.5	+ 5.0	− 5.1

These facts can be seen plainly on fig. 5, which reproduces the numbers of Table 12 in a graphic form. I have added a few arrows to suggest the probable flow of the cool and warm currents in the several levels. Thus, in the 10,000-meter level the cool current is from the northwest, in the middle levels, as 5000 meters, from the north, and in the lower levels from the northeast. The warm current is generally from the south with a smaller rotation from the southwest through the south to the southeast. I should like, in this connection, to call special attention to figs. 6 and 7 of my paper III: "The observed circulation of the atmosphere in the high and low areas," MONTHLY WEATHER REVIEW, March, 1902, where the results of the work of the Weather Bureau on the circulation during the International Cloud Year, 1896–7, were summarized. The observed vectors and the components which disturb the normal motion of the atmosphere are there given. Two characteristic features were then marked with the letter *A*, one on the northern quadrants of the cyclonic components, and the other on the southern quadrants of the anticyclonic components. *By comparing with fig. 5 of this paper, it will be seen that there is a rotation through about 90°, from the northwest to the northeast in the north quadrant, for both velocity components and for temperature variations in passing from the 10,000-meter levels to the surface; and that the rotation in the south quadrant is less in the respective cases. It is proper to infer that the two systems are mutually interdependent, and that the movement of the circulation is attended by a corresponding variation in the temperature distribution.*

At the time of constructing the chart of the velocity vectors, I was unable to explain its meaning, and as it differed radically from the charts of velocity-motion published by Mr.

Clayton for the Blue Hill observations, and by Professor Hildebrandsson for European observations, it was desirable that some criterion should be found which would indicate which configuration is to be accepted. My charts, as there explained, depended upon an asymmetric temperature structure of the cyclone and anticyclone, while the Clayton-Hildebrandsson charts seemed to favor a symmetrical system, such as Ferrel had assumed to exist in his theoretical discussions. The agreement, however, of these two independent sets of observations, velocity vectors by the Weather Bureau, and temperatures by Blue Hill, Hald and Berlin, would seem to indicate that the asymmetric system of currents must be adopted. While I can not claim that the numerical values of Table 12, and fig. 5, of this paper are entirely correct, it yet seems probable that the prevailing type of the temperature configurations in the several levels has been made out with sufficient definiteness to permit a numerical discussion of the data, with the aid of the thermodynamic equations in connection with the general dynamic equations of motion, such as will be attempted in the other papers of this series.

THE MEAN TEMPERATURE, T, IN CYCLONES AND ANTICYCLONES.

By means of the variations of temperature, ΔT, given in Table 12, using the mean temperatures of the second column, we can find the mean temperatures in each sector, N., E., S., W., of the high and low areas for summer and winter. The result is given in Table 13, mean temperatures, T, in cyclones and anticyclones. The same data are plotted on fig. 6, and lines dividing the warm and cold areas are drawn, which are similar to those in fig. 5. It is not necessary to make any extended remarks about the distribution of temperatures at this point, but the relations can be illustrated by fig. 7, on which the temperatures of Table 13 are suitably plotted for each sector, the dotted lines standing for the warm areas and the full lines for the cool areas. The scale of the temperature abscissas is smaller than in figs. 3 and 4 of the preceding paper, in order to extend the elevation to 10,000 meters instead of 6000 meters.

From Table 13 we can obtain the temperature falls in 1000 meters for each sector by subtracting the successive temperatures, and such temperature falls per 1000 meters, or gradients, may be taken as the true average for the middle of the stratum. On fig. 8, marked the temperature fall per 1000 meters in each gradient, these results are plotted at the middle distances between the 1000-meter levels, and they are connected up by proper curves, which form an interesting study. The first remark is that the result of the observations in the east sector of the high levels in winter and summer probably need to be modified, because the east line has escaped the concentration common to all the other lines. The second point is that the curvature of the lines indicates the prevailing cloud strata; that is where the lines slope upward to the right, and where the air is relatively warmer than the mean gradient would admit, a cloud formation takes place, as cumulus in the 1000–2000-meter stratum, cirrus in the 8000–10,000-meter stratum, winter and summer, and alto-cumulus in the 4000–6000-meter stratum in summer. These levels contain an especially large number of mixing currents of warm and cold masses, and the latent heat of condensation of vapor to water adds a certain amount to the heat transported from other regions. The third and most important remark is the fact that the temperature gradients in the atmosphere are very variable from one level to another, and that they are always smaller than the adiabatic gradient, 9.87, in these latitudes. In the latitudes farther south and in the Tropics, at least in the lower strata, the adiabatic gradient is, on the other hand, often less than that actually observed in the atmosphere. Such relations of observed to adiabatic gradients will form the key to my treatment of the thermodynamic formulæ in their application to the atmosphere. It is apparent that the Ferrel Canal Theory of the general circulation, poleward in the upper strata and equatorward in the lower strata, must be practically rejected or greatly modified in the following manner. The heat energy of the Tropics escapes toward the poles principally in two strata, the upper in the cirrus region, where there is mixing with cold currents from the poles, and the lower in the cumulus strata, where there is also mixing with the cold polar streams, while between these layers the intermediate strata are comparatively free from pronounced intermingling. The exact character and the extent of these operations in the cirrus level remain to be more fully investigated by suitable observations, which are required before the needed details can be secured. Especially in the tropical zones it is important to procure accurate thermal gradients up to high levels. The final solution of the problem of the circulation of the atmosphere is dependent upon such an exploration of the temperature conditions, because from these data alone can the corresponding pressure and density be computed.

TABLE 13.—*Mean temperatures, T, in cyclones and anticyclones.*

Height in meters.	Mean temperature.	High areas.				Low areas.			
		N.	E.	S.	W.	N.	E.	S.	W.
WINTER.									
	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.
10000	—54.2	—55.2	—56.2	—53.7	—52.2	—52.0	—51.2	—56.2	—57.0
9000	—47.7	—48.2	—50.2	—46.8	—45.3	—45.7	—44.7	—49.9	—50.7
8000	—40.6	—40.6	—43.6	—39.3	—37.6	—39.1	—37.9	—43.1	—43.9
7000	—33.6	—32.9	—37.1	—32.1	—29.6	—32.4	—31.1	—36.2	—37.1
6000	—26.7	—25.3	—30.7	—25.5	—21.7	—25.6	—24.5	—29.5	—30.5
5000	—20.0	—18.0	—24.6	—20.0	—14.3	—18.8	—18.0	—22.8	—24.0
4000	—14.3	—11.5	—18.6	—15.5	— 8.7	—12.5	—12.5	—16.7	—17.8
3000	— 9.0	— 6.3	—13.0	—10.3	— 4.2	— 6.8	— 7.6	—11.3	—12.4
2000	— 4.2	— 2.2	— 8.0	— 6.0	— 0.2	— 1.8	— 3.0	— 5.5	— 7.2
1000	— 0.6	+ 0.9	— 3.7	— 3.1	+ 2.7	+ 1.1	+ 0.7	+ 0.5	— 2.8
0	+ 3.6	+ 4.2	+ 1.5	+ 0.1	+ 5.6	+ 4.5	+ 4.7	+ 6.5	+ 1.9
SUMMER.									
10000	—46.9	—48.1	—48.4	—46.7	—45.9	—42.1	—45.7	—48.9	—49.4
9000	—40.1	—40.7	—42.1	—39.6	—38.6	—35.5	—38.9	—42.4	—42.9
8000	—32.8	—32.8	—35.3	—31.8	—31.0	—28.4	—31.8	—35.5	—35.8
7000	—26.1	—25.4	—29.1	—24.6	—24.1	—21.9	—24.9	—29.1	—29.3
6000	—19.9	—18.5	—23.2	—18.7	—17.5	—15.9	—18.5	—22.9	—23.4
5000	—13.6	—11.7	—16.8	—13.7	—10.8	—10.3	—12.2	—16.3	—16.6
4000	— 7.2	— 4.9	—10.4	— 7.7	— 5.0	— 4.4	— 5.9	— 9.2	— 9.8
3000	— 0.9	+ 1.0	— 3.8	— 1.3	+ 1.1	+ 1.5	— 0.6	— 1.9	— 3.5
2000	+ 4.3	+ 5.7	+ 2.1	+ 3.9	+ 5.9	+ 6.2	+ 4.5	+ 4.3	+ 1.9
1000	+10.0	+10.5	+ 8.1	+ 8.8	+11.0	+11.2	+10.4	+11.0	+ 7.8
0	+15.7	+15.9	+14.1	+13.7	+16.1	+16.5	+16.5	+18.5	+14.2

RESUME OF THE TYPICAL DISTRIBUTIONS OF THE VELOCITY, TEMPERATURE, AND PRESSURE IN CYCLONES AND ANTICYCLONES.

Having described the typical distribution of the velocity in the local circulations, as in the International Cloud Report, 1898, or the MONTHLY WEATHER REVIEW for March, 1902, the pressure distribution, as in the MONTHLY WEATHER REVIEW for February, 1903, and the temperature in this paper, it will be proper to summarize the results schematically, as in figs. 9 and 10. The former gives the resultants of the general circulation in the north temperate latitudes plus the local component disturbances, and the latter simply the components by themselves, separated from the prevailing eastward drift. In fig. 9 the velocity is seen to diverge more and more from the eastward direction in the higher levels, and gradually to break up into the well-known cyclonic and anticyclonic gyrations in the lower levels. The anticyclone has a system of outward components from top to bottom, and the cyclone a system of inward components from bottom to top, but in neither case can there be any true inversion in the type of the system. The temperatures show that the wave motion is intensified on approaching the surface, as the strong eastward drift is gradually diminished in the lower levels. The pressure, on descending from one level to the other, in the same way gradually takes on the well-known features of the high and low pressure areas, the high areas standing with the "saddle" toward the south, and the low areas with the "saddle" toward the north. The *closed* isobars decrease in density from the surface upward, and disappear at two or three miles above the ground, being depleted at the top by penetration into the eastward drift. Whenever closed isobars occur there is a vertical component of the circulation, downward in anticyclones, upward in cyclones. There is evidently very little vertical movement in the upper levels of the atmosphere, where the isobars are mere wavy lines, unless some unobserved closed isobars occur, as is probably the case in the development of hurricanes in the Tropics.

In fig. 10 the disturbing components are given for the velocity, temperature, and pressure. In the velocity of the anticyclone there is a gradual transition of the known outflowing structure at the surface into a simple loop in the upper levels, the orientation being changed only a little; in the cyclone the inflowing components are better preserved from the surface to the higher levels, but there is a distinct rotation of the structure through about one quadrant. The temperatures show the maximum disturbances on the boundary of the high and low areas, with a distinct rotation of both the cold and warm areas through one quadrant. The pressure disturbances consist of closed isobars gradually diminishing into loops in the higher levels and rotating through one quadrant, especially in the cyclone. In one aspect the analytical solution of this dynamic structure is simpler than that demanded in Ferrel's or in Guldberg and Mohn's adopted types of vortices, but it is certainly different from either of them. It is evidently necessary to distinguish carefully between the cyclonic system proper and the resultant system formed by its combination with the general eastward drift, so that the mathematical analysis shall not deal with the components and resultants indiscriminantly. It is not proper to appeal to observed resultant motions in the atmosphere in verification of a theory applying solely to the components, namely, the cyclonic and anticyclonic gyrations as examples of a special form of vortex. Having thus found at least an approximate system of correlated velocities, temperatures, and pressures in the atmosphere, it will be possible to approach the mathematical analysis of the structure with some prospect of a satisfactory solution.

VERTICAL AIR CURRENTS.

By FRANK W. PROCTOR. Dated Fairhaven, Mass., January 28, 1906.

In the MONTHLY WEATHER REVIEW for September, 1905,[1] Mr. Clayton mentions two instances of vertical air currents having considerable lifting power. Both occurred on mountains, and Mr. Clayton expresses the opinion that "it is probable that near the ground over a level country the air can have no great vertical motion, except in whirlwinds, so that phenomena of this kind are not observed."

The writer has observed one case of a descending vertical air current in a valley, which seems to be a precise counterpart of the current that lifted Mr. Eddy's kite vertically about 1000 feet above Blue Hill, as described by Mr. Clayton. It was in summer, and the writer was flying a Hargrave kite of the Weather Bureau pattern, standard size, without any load, at Andover, N. H., in the valley lying between Ragged and Kearsarge mountains. These mountains rise 1400 and 2400 feet, respectively, above the level of the valley floor, which is narrow at this point.

Upward of 2000 feet of wire were out when the line apparently broke, and the kite fell rapidly and disappeared. The line of flight was across a river, and in order to prevent if possible the wire from sagging into the river and getting wet, the line was reeled in as rapidly as possible. With no tension on the wire, and a reel that took in approximately five feet at every turn, the line came in pretty fast. After about 500 feet had been reeled in, the kite was seen to rise, and it was then discovered that the line was not broken, and that the fall of the kite was due to a descending air current.[2]

At another time on a summer day at the same place, this kite, while flying at an ordinary angle, rose and passed the zenith at a height of about 1000 feet, being lifted by a vertical current. There was no cloud overhead.

The writer has several times had toy kites lifted by vertical currents during summer anticyclonic weather, while flying at levels from 100 to 300 feet, over the south shore of Massachusetts, where the ground is tolerably level. From the fact that in the nonenergetic summer areas of high barometer falling currents are rarely seen, while rising currents are not rare, it seems to be a fair inference that at this time of year the slow descent of large masses of air is offset by the more rapid ascent of small masses. These small rising masses are probably too irregular in horizontal section and too evanescent to generate whirls.

SNOW FORMED BY MIXTURE OF WARM AND COLD AIR.

By RICHARD W. GRAY, Assistant Observer, Weather Bureau. Dated Atlantic City, N. J., February 7, 1906.

At Atlantic City, N. J., on February 6, snow, in the form of minute flakes, fell continuously from 10:45 a. m. to 3:30 p. m., the sky during this period being perfectly clear. At intervals, and for periods of from one to two minutes, the flurries were quite heavy, and, except for the size of the snowflakes, had every appearance of an ordinary snowstorm. Condensation seemed to take place at a low altitude (probably not more than 75 or 100 feet above the ground), and had practically ceased at the elevation of ordinary buildings.

The unusual condensation was evidently caused by the mixing of relatively warm and moist air from the ocean with the colder air over the land. The wind, during the occurrence of the phenomenon, was from the northeast; the temperature ranged from 15° to 22°, and the relative humidity averaged about 70 per cent. Strato-cumulus clouds began to form about 3:30 p. m., at which time the snow ceased.

It is generally taught that rain and snow are formed principally by the cooling due to the expansion of rising moist air; still it is also recognized that small amounts of rain or snow can be formed by the cooling due to the radiation of heat during the nighttime, but the quantities formed are small, the process is slow, and the radiation is itself checked by the haze or fog or thin cloud that accumulates, so that the radiation can only take place from the upper surface of a cloud.

Precipitation can also take place by the intimate mixture of warm and cold moist air, and, if the masses and temperatures are properly adjusted, light snow may be formed in this case. It frequently occurs in the winter months that a mass of clear, cold air, moving southward from Canada, encounters a corresponding mass of warm, moist air in the United States, and the pressures and densities are so well adjusted that we have a well-defined band trending east and west, showing gentle southerly winds on the south side, and gentle northerly winds on the north, with a belt of cloudy air separating them, over which light rain or snow occasionally falls. Eventually, some-

[1] Pages 390-91.

[2] Would not a simple failure of the wind have produced the same drop of the kite and wire?—*C. A.*

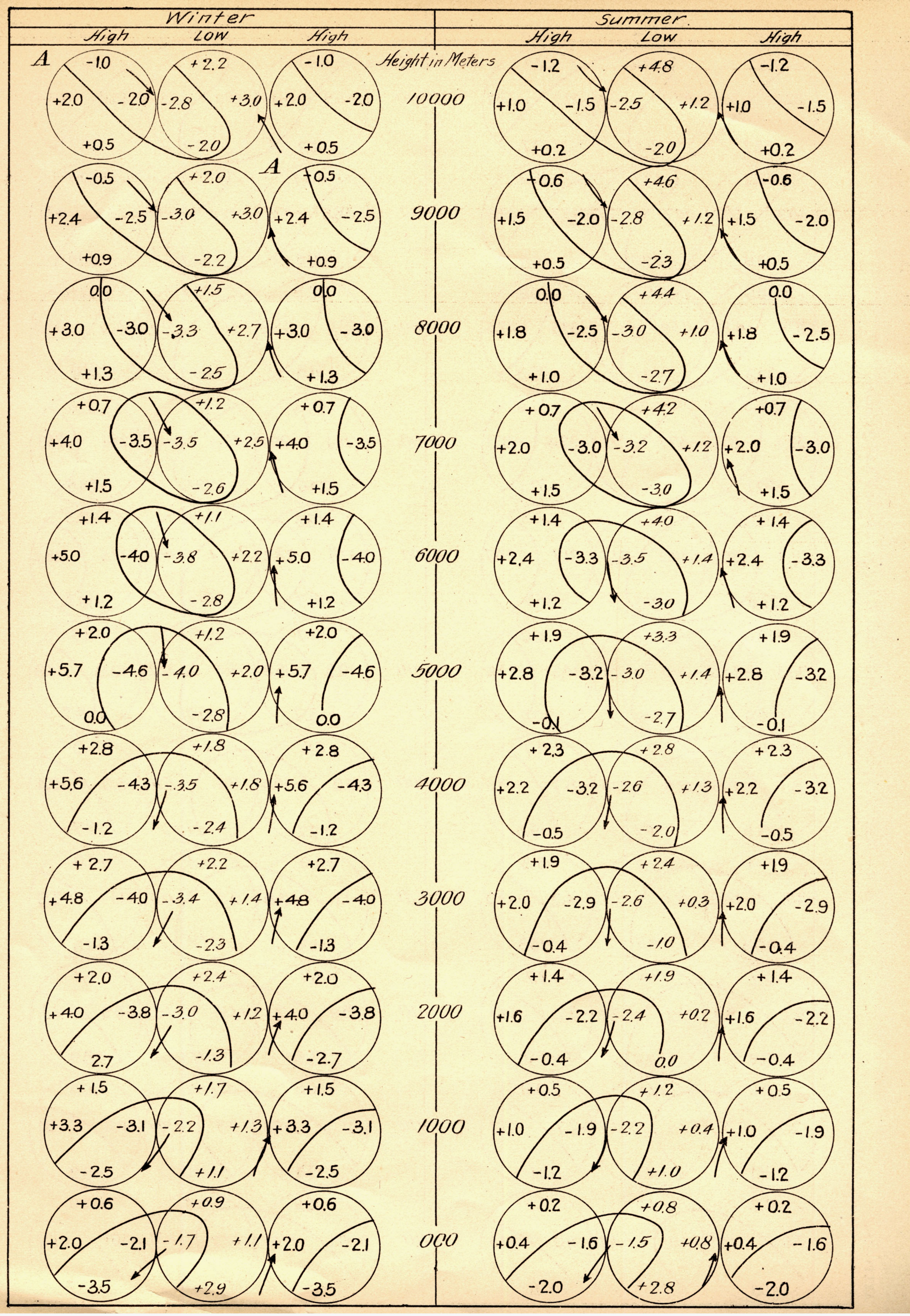

FIG. 5.—Mean Temperature Variations, ΔT, in American and European Cyclones and Anticyclones.

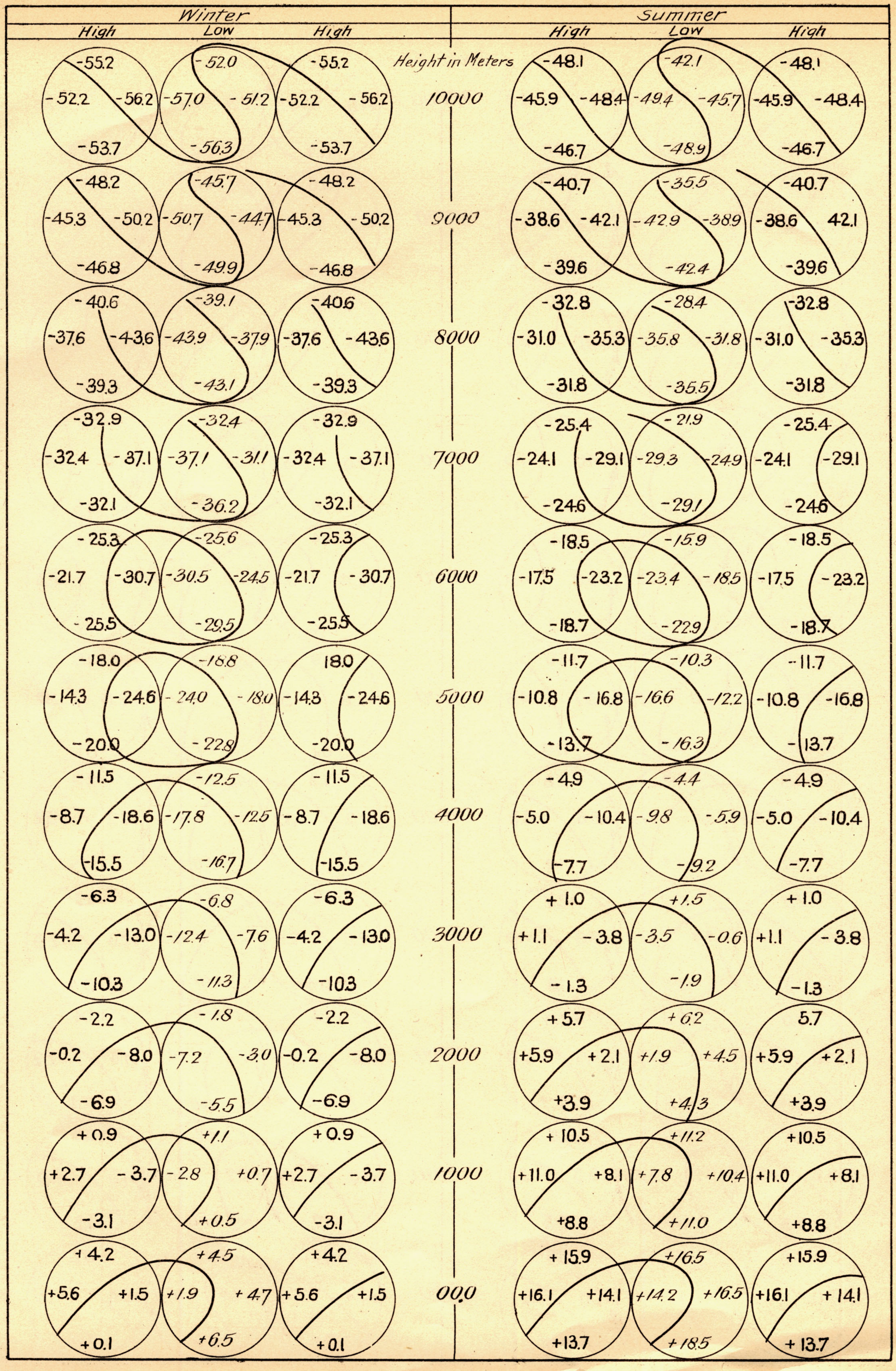

Fig. 6.—Mean Temperature Distribution, T, in Cyclones and Anticyclones.

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FIG. 7.—Adopted Temperature Distribution, Derived from the Mean American and European Observations.

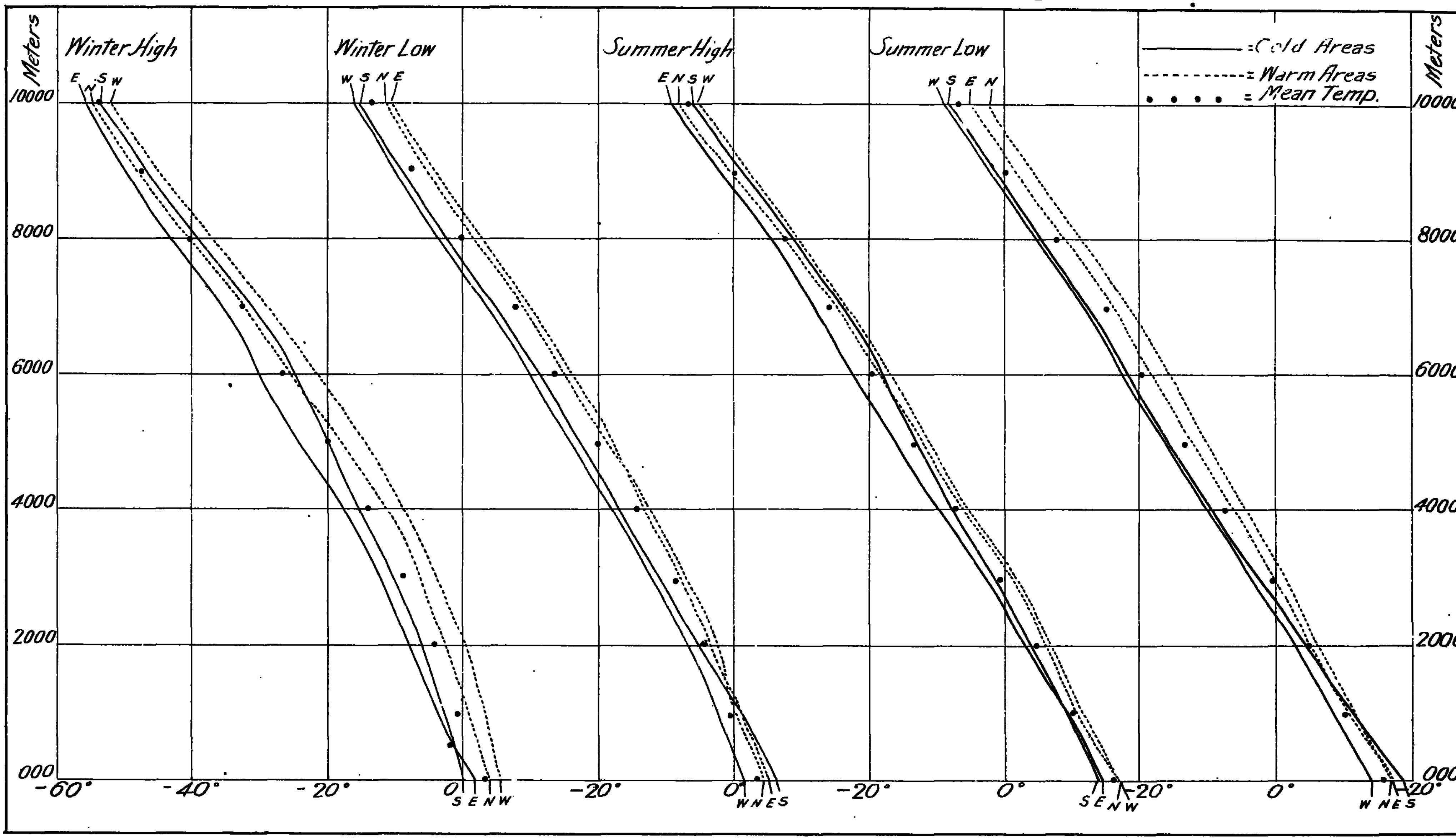

FIG. 8.—Temperature-fall per 1000 Meters in Each Quadrant. (Latitude +40° to +60°.)

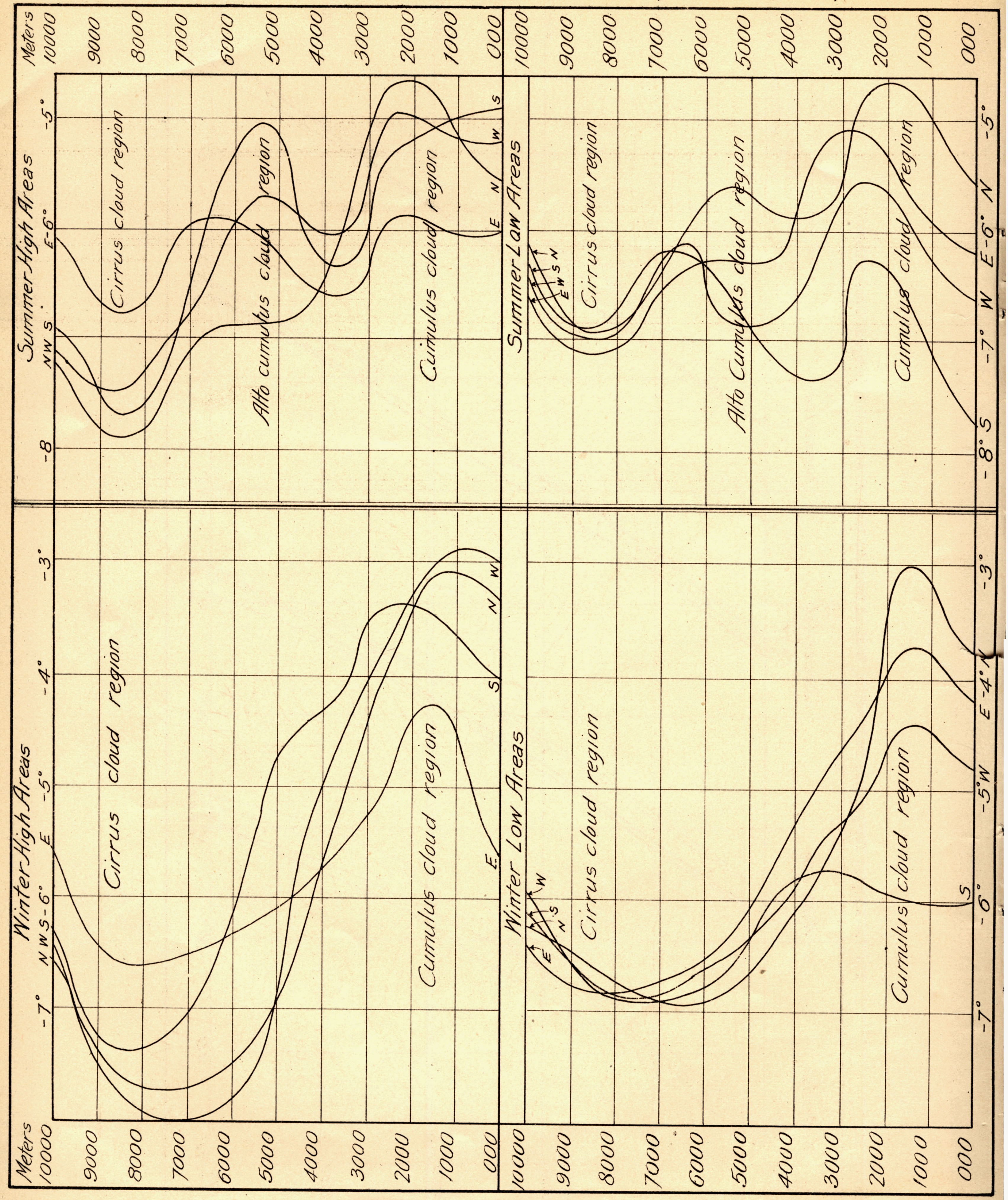

FIG. 9.—Typical Distribution of the Velocity, Temperature, and Pressure in Cyclones and Anticyclones.

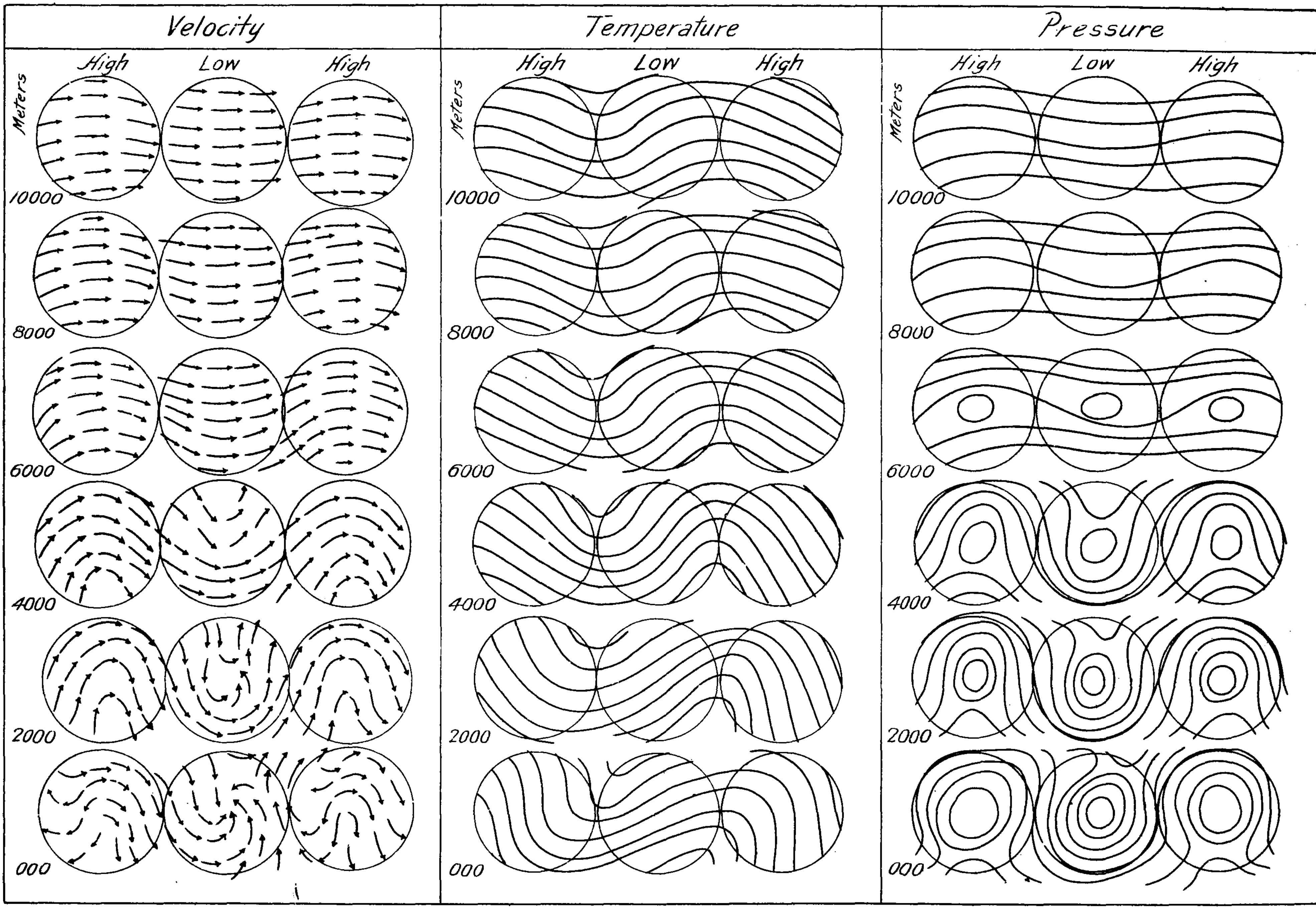

Fig. 10.—Typical Distributions of the Cyclonic and Anticyclonic Components of Velocity, Temperature, and Pressure.